May 2002 • NREL/SR-510-31970

Subcontractor Report

SUGAR PLATFORM COLLOQUIES

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List of Acronyms and Abbreviations

ADM	Archer Daniels Midland
ARS	Agricultural Research Service
CGF	corn gluten feed
DDG	distillers dry grains
DOE	U.S. Department of Energy
dt	dry ton
EPA	Environmental Protection Agency
NRCS	Natural Resource Conservation Service
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
R&D	research and development
RFP	request for proposal
TVA	Tennessee Valley Authority
USDA	U.S. Department of Agriculture

Executive Summary

Four colloquies were held in late 2001 to discuss what is needed to accelerate lignocellulosic biomass based products from sugar fermentations to commercialization and how the Department of Energy (DOE), the National Renewable Energy Laboratory (NREL), and other government actions can help.

Each session brought together participants with a general knowledge of the issues but different individual expertise—a multidisciplinary group that were in a position to influence the future direction of the industry. They represented the following industry segments:

- Chemical companies
- Enzyme producers
- Corn wet millers
- Microbe developers
- Potential biomass suppliers
- Life science companies
- Petroleum industry

The topics discussed in the colloquies were:

- Feedstock availability, collection, and storage
- Economic process
- Process validation
- Commercialization timeline
- Market outlook
- Environmental factors
- Government actions

Major topic findings were related to feedstock, sustainability, and the need for the initial commercialization to have industry leadership.

Feedstock: Plants will be located near low-cost, reliable and abundant feedstock like crop residues, particularly corn stover. Improved harvest and storage methods will increase supply reliability, return more than $20/acre income to the farmer, and reduce delivered cost from $35/dry ton delivered to $25 or less.

Sustainability: The sustainability profile for feedstock production and harvest needs to be researched and balanced with alternative applications down the value chain. Improved awareness of the environmental impact is needed.

Industry Leadership: Biomass hydrolysis development and demonstration requires industry leadership. Companies from the chemical industry are strong prospects for leadership roles because of their R&D spending, technical capabilities, and need for sustainable processes.

Initial Commercialization: Industry will be likely to form partnerships to develop proprietary technology for first plants. A consortium is less likely.

Key government actions to accelerate the commercialization effort will include:

- Supporting process development and demonstration as a resource provider, assisting industry partners to become the technology supplier
- Recognizing that the development and demonstration of an economic biomass hydrolysis process will likely cost $50 million or more in capital and research expense and scale solicitations that recognize this cost
- Setting the goals to be accomplished and soliciting cost shared proposals from industry to reach them.

Feedstock

Corn stover and other crop residues are the most likely feedstocks. Considerable sugar cane could be available if the process economics can be demonstrated. Switchgrass may emerge as more sustainable in the long term when the yield is improved without “inputs” required for cash crops.

There appear to be no “show-stoppers” for obtaining corn stover and straw throughout the year in a manner beneficial for both farmer and processor. A price in the $35 to $40/dry ton can be delivered within a 50 mile radius. One-pass harvest and bagasse type storage is likely to reduce this to below $25 while still returning $20/acre income or more to the farmer.

Unresolved issues revolve around sustainable harvest. An extended knowledge of the removal impact is needed that account for anticipated changes in the crop management and harvest practices.

Plant science offers significant opportunities to improve yield and lower cost are most likely to be realized in the mid to long term (5 to 10 years in the future).

Economic Process

Development of an economic process is a major concern, more than feedstock cost and availability. Industrial partners are needed to set the development direction. Pretreatment is the most critical process step. A multi-disciplinary approach that couples biotechnology and chemistry with process engineering will achieve best design and cost.

Pretreatment and enzyme hydrolysis development need to be linked now. Unless the substrate from the pretreatment closely matches that from the full scale pretreatment scheme, the enzymes developed may not achieve the same performance in a commercial plant.

A small, integrated corn stover feedstock process must be operated to better determine the following:

- Feedstock variation effect
- Pretreatment condition limits
- Assess enzyme hydrolysis
- Fermentation microbe performance
- Improve cost estimate
- Fix design for next plant scale

A pilot plant with a feed rate between a kilogram and one ton per day needs to operate continuously for design confidence—closing carbon and other material balances, establishing process yields and stream composition, testing materials of construction, yields, and providing more fundamental and macro knowledge.

Process Validation

Following the small scale demonstration, an intermediate scale plant is needed to reduce risk for potential investors and other stakeholders including employees, feedstock suppliers, and customers associated with building the “first-of-a-kind” commercial plant costing about $200 million.

Process guarantees provided by the design engineering companies are not an adequate substitute. The guarantees are expensive and have not helped their holders to access capital for biomass plant projects that have skipped the intermediate scale process validation step.

Continuous operation on a “semi-commercial” scale demonstrates the design basis and better insures that the larger process design will produce a quality product that meets the customer requirements safely, within budget, and complies with all environmental requirements.

The scale-up factor using stover and other crop residues is likely to be 20 to 50X for the pretreatment step and 1,000X or more for fermentation. The estimated cost is $40 to $50 million when co-located with an existing industrial facility. Products from the demonstration plant are not expected to cover the operating cost.

Wet millers may be able validate corn fiber conversion for a lower cost. Since the composition and physical properties of the fiber are significantly different from crop residues, using this route as a prologue to residues is not likely.

Industrial participation can take several forms, including consortiums, partnering and leasing. A consortium was too expensive and complex to function and meet most potential member's needs. Participants already working in the area preferred partnering with others that leverage their expertise. Funding the construction of a large government facility, similar to the 40 dt/day Iogen plant and leasing it to others was not considered plausible.

Commercialization Timeline

There are multiple biomass commercialization plans underway. NREL's schedule matches up with the improved enzymes expected to be available in 2003 and 2004 from Genencor and Novozymes. Others have similar plans for a commercial plant in the next 3 to 5 years. Iogen has announced plans to have a commercial ethanol plant underway by 2004-2005.

NREL indicated it would hold a meeting to discuss the timeline and related issues in January, 2002. All the colloquy participants will be invited to attend, as will other interested parties.

Market Outlook

Fuel ethanol and chemicals are the target markets. The fuel ethanol market is subsidized, at least until 2007, but chemicals are not. Both require additional government support to become a commercial reality in the timeframe described previously.

Participants said the price—8¢ to 9¢/lb—for fermentation sugars from corn and other grains limits commercialization. Advances in biotechnology have resulted in process routes that were previously impossible. The processes become economic at 3¢ to 5¢/lb without government support. Many of the products now produced from petroleum feedstocks could be moved to a biobased process.

The huge scale for these products makes the market for by-products difficult to develop and manage. By-product quantities can easily exceed their market needs. As a result, most of the lignin is expected to be used as a boiler fuel.

Environment

The chemical industry is pursuing sustainable development as an integral extension of their business. In terms of the "triple bottom line," projects must produce financial returns while meeting corporate environmental and social objectives and goals. "Natural capital" and "social capital" are more difficult to appraise. Natural capital is measured in environmental terms. Social capital measures are more qualitative.

Cleaner technologies like biotechnology are being emphasized—e.g., teaming biotechnologists with traditional process design people to create new technology platforms. The effort is likely to speed up as greenhouse gas emission rules are implemented.

Conclusions

The program to commercialize biomass to ethanol is largely on track. Plans to reduce feedstock costs by nearly 50% are in place. Enzyme and ethanologen development continue as planned. The two largest issues remaining are:

- Integrating the process development
- Attracting industrial participants to co-fund the validation stage

More integrated development will be needed before risking a $200 million investment for the first plant. This development needs industry direction and participation. To overcome these barriers, establishing a "sugar platform" using the enzyme hydrolysis route under development by NREL and others appears to be most promising.

The risk can be reduced by operating an intermediate sized plant continuously to validate the design. The validation costs are high—$40 to $50 million—requiring industry partners with financial and technical resources to move ahead even if future government funding and technical support declines.

Developing a process that provides fermentation sugars for producing fuel ethanol and other chemicals expands commercialization interest to include the chemical industry. Their participation brings additional technical and financial resources that can strengthen the effort.

Recommendations for Government Actions

Participants are looking for government actions to help reduce the risks associated with building the first plant. The major areas for assistance they recommend are:

- Process development—continuing to integrate the process, providing additional understanding at a fundamental and macro level
- Sustainable feedstock collection—going beyond erosion control and carbon sequestration in the soil
- Process validation—funding multiple process validation efforts via cost-shared government/private sector efforts

NREL is scheduling a January, 2002 meeting with colloquy participants and other interested parties to better frame the request for proposal (RFP) contents. In addition, letters of interest should be requested from interested parties describing how they would like to partner to accomplish this. Other recommendations include the following:

<u>Process development</u>

The National Laboratories, particularly NREL, should continue process development with a focus on corn stover. These activities are best directed by industry so that the results are commercialized. Partnering with industry is necessary, and DOE/NREL can pass intellectual property to their industrial partners.

Sustainable feedstock collection

Feedstock sustainability issues require better resolution. Previous studies of crop residue removal need to be revised to include other factors in addition to soil erosion and carbon sequestration.

Process Validation

Colloquy participants suggested that DOE should issue and fund multiple RFPs, and that they should be funded for process validation after framing the RFP contents with industry participation. While no consensus is expected, solicitation of industry's interest can produce more targeted solicitations.

Coordinating RFPs within Energy Efficiency and Renewable Energy (EERE) offices and with other departments is desired. The objective and goals for the RFP should be clearly stated. Supporting information should be included that comprehensively covers the current process technology base. Allow adequate time to respond. Organization of the RFP effort needs to be flexible.

The selection criteria should be set to help insure that partners have the necessary resources to complete the work. It should be clear that funding over multiple years may not be available. Since Congress fixes the federal budget on an annual basis, there is no assurance that DOE funding will be adequate in future years to support the projects.

Selection should also be based on the ability to clearly extend the outcome to a large market segment without much additional work. For example, one criterion could be that the feedstock selected along with the pretreatment process will allow hydrolysis to sugars adequate to supply 5% or more of the transportation fuel market along with meeting the needs of chemical and polymer producers for relatively consistent and pure fermentation sugars.

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1. Introduction

The present ethanol industry has grown rapidly using grain, mainly corn, feedstocks. Corn conversion to ethanol is widely supported as a way to improve the rural economy, decrease our dependence on fossil fuel imports, and improve the environment.

Biomass to ethanol and other products like chemicals produced from fermentation sugars are also emerging to meet the growing demand for more sustainable processes. Initially, collecting crop residues, particularly corn stover, appears to be the most promising route based on the efforts to date. Additional industry participation and direction are needed for commercialization.

To explore the possibilities with industry, four colloquies were held with small multidisciplinary groups of industry representatives. The purpose was to define the actions needed to accelerate lignocellulosic commercialization of biomass based products from sugar fermentations and to determine how the Department of Energy (DOE), National Renewable Energy Laboratory (NREL), and other government agencies can help.

<u>Corn feedstock</u>

Corn for ethanol is expected to eventually supply 6 billion gallons or more of ethanol. Production capacity has increased from less than 1% of the 160 billion gallon transportation fuel market—1.4 billion gallons in 1998—to 2.4 billion gallons in 2001. About 7% of the U.S. corn crop is now used for ethanol.

While this projection represents barely 4% of the transportation fuel market, the marketability of by-products from increased corn processing is a concern to some producers. Each bushel of corn produces about 17 lbs of distillers dry grains (DDG), and 13.5 lbs of corn gluten feed (CGF), from the dry and wet milling processes respectively. While dry mills are expected to account for most of the future expansion, any excess of these feeds can effect the feed market of both—the price drops, adversely impacting ethanol production cost.

Others do not see this as an issue as long as the quality of DDG and CGF are consistent. A recent study (Urbanchuk, 2001) projects corn for ethanol increasing from 652 million bu to 2.5 billion bu by 2016 with modest impacts on the by-product market. DDG and CGF simply replace corn in the ruminant animal’s diet. The study predicts that corn for ethanol use above 2.5 billion bu, or nearly 7 billion gallons of ethanol, might have some adverse impact on by-products. There may also be an increasing demand for corn in order to meet the world’s food supply needs.

<u>Biomass feedstock</u>

Additional ethanol can be produced from other biomass to supplement the fuel transportation market. Biomass—corn stover, cereal straw, energy crops, and forest trimmings—has been identified as a widely available lignocellulosic feedstock suitable for conversion to low cost fermentation sugars. Sustainable removal of these feedstocks can produce another 10 billion gallons of ethanol in addition to chemicals. However, the conversion remains unproven on a large scale. The risk for a first plant using this technology is presently judged to be too great. More process development work is required to reduce capital investment and operating costs.

<u>Industrial participation</u>

While the DOE's National Laboratories, especially NREL and Oak Ridge National Laboratory (ORNL) have large biomass based development efforts, industrial partners are necessary for commercialization. The risk for the first plant is substantial. The plant investment will be about $200 million (Wooley et. al., 1999). Further development, matching government funds, and other actions can reduce the risk and encourage commercialization to move ahead.

The development costs required from industry are substantial. Even with matching government funds, the partner's share can easily cost $20 to $25 million for just the process validation step. The chemical industry has more resources to broach this need, and will probably partner with others to provide the multidisciplinary capability required.

The ethanol industry has limited resources to support this effort due to the nature of the commodity business. With small profit margins, typically 1% to 4%, little is spent on development. For example, the largest ethanol producer, ADM with total corporate sales over $20 billion in 2001, spent 0.12%, or $24 million, for all of their process development. In previous years their total development costs were approximately $23 and $22 million respectively. Other producers spend less; amounts so small that they are usually not reported in their Security Exchange Commission filings.

The chemical industry has higher margins and spends 4% to 8% of its revenue on research and development. The total R&D of just three of the companies that participated in the colloquies exceeded $2.1 billion (Appendix A).

The chemical industry has a number of drivers for moving to a biobased platform:

- Improving financial results
- Reducing dependence on petroleum feedstocks
- Reducing environmental impact

The profit margins of the industry, once more than 12%, have dropped to about 7%. Most companies are barely earning a return on investment. A survey of the 40 major U.S. chemical producers (C&EN, 2001) showed the average profit margin was 7.1% for the year 2000, declining from 7.4% in 1999. Only seven of the companies surveyed had margins above 10%, and they were just slightly in the double digits. Return on investment was a low 4.7%. In addition, the uses for petroleum derived feedstocks subject them to volatile pricing swings and environmental pressure.

The opportunity presented by low cost biomass, biocatalysts, genetically enhanced microbes, and plants has been recognized by the chemical industry. Some of these efforts are summarized in the following (see References).

- Chemical Industry Technology Vision 2020
- Plant/Crop Based Renewable Resources 2020
- New Biocatalysts: Essential Tools for a Sustainable 21st Century Chemical Industry

Based on their higher R&D funding, current drivers, and the industry's recognition of renewable feedstock opportunities, it appeared that a common objective could likely be formulated to commercialize value-added chemicals and polymers with fuel ethanol from biomass using low cost fermentation sugars as the feedstock.

Colloquies

To explore these possibilities, four colloquies were held in October and November 2001 to discuss the sugar platform possibilities—what is needed to accelerate lignocellulosic biomass based products from sugar fermentations to commercialization, and how the DOE and other government agencies can help.

Each session brought together seven to ten participants that had a general knowledge of the issues but different individual expertise—a multidisciplinary group that were in a position to influence the future direction of the industry.

A list of participants is provided in Appendix B. They represented the following industry segments:

- Chemical companies
- Enzyme producers
- Corn wet millers
- Microbe developers
- Potential biomass suppliers
- Life science companies
- Petroleum industry

Commercialization timelines were reviewed. The topics discussed in the colloquies are listed below.

- Feedstock availability, collection, and storage
- Economic process
- Process validation
- Market outlook
- Environmental factors
- Government actions

Several items were included from the Biomass Commercialization Outlook (Hettenhaus, 2000) and the Yeast Platform Project (Johnson, 2001) to help insure that we were using the same basis as most of the participants had not previously attended a colloquium.

2. Feedstock Issues

All participants agreed that in addition to corn, crop residues were the most likely feedstock source for producing billions of gallons of ethanol annually in the next 5 years. Corn stover and straw were thought to be the best candidates. Sustainable removal, collecting adequate corn stover after the grain harvest, and costs raised some concern, but participants thought that there were no supply show-stoppers. Better guidelines for sustainable removal are needed, looking beyond erosion control and carbon sequestration to life cycle analysis.

The surface residue contains dirt and the collection window shortens greatly as the harvest moves north. These problems along with degradation in storage and bale associated fire hazards can be overcome by a one pass harvest and bulk, bagasse type storage.

Plant science offers additional opportunities in the mid- to long-term. Most participants were comfortable with business models linking farmers and processors in win-win relationships.

<u>Feedstock Sources</u>

a. Corn stover

Corn is the largest grain crop in the U.S. and 50% of the crop, about 250 million dry tons, is left in the field after harvest. This surface residue, termed corn stover, is available as feedstock without additional land use. While there are ongoing studies underway by the U.S. Department of Agriculture (USDA) and others to better determine the sustainable amount of stover that can be removed, there is good assurance that more than half is available at a cost of $35 to $40/dt delivered within a 50 mile radius (AD Little, 2001). As a result, corn stover is the focus for DOE related feedstock efforts.

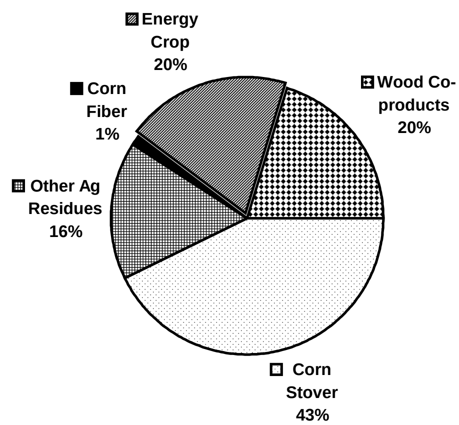
The ORNL feedstock program and staff have expanded to meet this need. Several projects have been funded to develop “single pass harvest” of the corn crop, which is expected to reduce the cost further, approaching $20/dt delivered.

Single pass harvest reduces soil compaction and shortens the stover harvest window as the stover does not need to remain in the field to dry for baling. It eliminates the dirt, fire hazard, and higher rate of degradation encountered with bales. The entire corn plant would be harvested, leaving enough of the plant to comply with erosion control. The remaining stover would be stored in bulk similar to bagasse (Atchison, 1972).

Other crop residues, such as rice straw and other cereal straws represent less than half the amount of stover (Figure 1). The high silicon content in rice straw makes it more difficult to process. A summary is found in Table 1.

Table 1. Biomass Available at $50/Dry Ton or less Millions of dry tons				
Corn Stover	Other Ag Residues: Straw, SB Stubble	Corn Fiber	Energy Crops	Wood Co-Products
153	**58**	**4**	**70**	**72**

Figure 1.



b. Corn fiber

Corn fiber is being processed on a pilot basis by several companies including Williams BioEnergy and ADM. Their effort is partially funded by DOE. While some participants felt a corn fiber process could readily be applied to corn stover, others discounted it for the following reasons:

- Composition and material consistency differences
- Price of material
- Processing history

Corn fiber contains a small amount of lignin and a large amount of bound starch as shown in Table 2.

Table 2.
Corn fiber and stover composition, dry basis

Cellulose	12 to 18%	32 to38%
Hemicellulose	40 to 53%	28 to 32%
Lignin (Phenolic)	0.1 to 1%	15 to 17%
Starch	11 to 22%	None

Corn fiber is sold as gluten feed when mixed with steepwater. Its price has varied from 0.7 to 1.2 the price of corn over the past 10 years. The market had a precipitous decline in 1997 and 1998, to 0.5 the price of corn in some areas. The decline was largely attributed to feed from Bt enhanced corn being discounted in the export market. The market has partly recovered, and some corn processors are now selling feed for $90/ton by using nutritionists to market a more consistent product (Perrins & Klopfenstein, 2000). As a result, these sellers are receiving a price closer to its feed value relative to corn for ruminant animals. Others in the industry are likely to follow this strategy.

Feed fiber has a significantly different processing history. Unlike stover, corn fiber has been “steeped” for 12 hours or more in a low pH solution at high temperature. It is relatively homogeneous. In contrast, baled stover enters the process at 12% moisture at ambient temperature with no previous processing.

c. Bagasse
Bagasse is the remainder of the sugar cane plant after the sucrose is extracted at the sugar mill. Bagasse is burned for process energy needs, often inefficiently just to dispose of it. For those mills without co-generation, about 1/3 of the material would be available through energy conservation.

During the sugar cane harvest, 20,000 tons per day or more are delivered to the mill for processing. This is 10X the amount of feedstock expected for the initial stover or straw based plants. The harvest in the U.S. begins in September and stops shortly after the first killing frost. When the sugar cane plant dies, the sugar in the plant begins to ferment, making it unsuitable for sucrose extraction.

Today, just 6 million dry tons of bagasse are produced in the U.S. and nearly all of it is burned. If burned efficiently, only enough for several plants would be available. Much more cane could be grown if a market for the sugar existed or if the economics for conversion to fermentation sugars were demonstrated.

Presently the sugar market is distorted through tariffs, NAFTA agreements, and World Trade Organization rules. The future will become especially bleak for U.S. growers when the Mexican sugar import restrictions expire in the next several years.

Switching to a “high fiber cane” that is not suitable for sugar extraction but better for biomass conversion may open up a considerable opportunity for the growers. The high fiber cane triples the biomass available, to 110 tons/acre. Since the higher fiber content decreases the sucrose yield, it only becomes attractive when the bagasse can be processed to higher value products. Bagasse has a composition close to corn stover. It was surmised to have similar pretreatment and hydrolysis processing characteristics.

d. Other feedstocks
Process waste from other sources was also mentioned as a possibility, especially for niche situations. Volumes are small and, like corn fiber, there was no consensus on whether these would be precursors to accelerating large scale commercialization and producing billions of gallons of fuel ethanol and millions of tons of chemicals and biopolymers.

Switchgrass may be more sustainable in the long term when the yield is improved without the “inputs” required for grain crops. Dryer regions would especially benefit if these developments were successful. Unlike stover and straw, switchgrass is not widely available, but it could be. Previous experience in introducing new crops indicates that farmers are not likely to change what they grow based on the promise of a new plant. When there is a plant, they may come around. (Ugarte et. al., in press. McLaughlin et. al., in review)

Sustainable Removal
Current erosion control and carbon sequestration models are not comprehensive enough. No processor wants to be associated with a harvesting operation without knowing the potential impact of removing the biomass, particularly corn stover.

Crop residue removal was studied nearly 25 years ago after the first Arab oil embargo (Larson, 1979 and Lindstrom et. al. 1981). To prevent soil erosion, some crop residue is needed on the surface. The amount required varies and depends on many factors such as slope, length of slope, and management practices. These characteristics have been modeled by the USDA and are readily applied and can be relied upon for controlling soil erosion.

For soil carbon sequestration, the Century model is generally accepted for most situations (http://www.nrel.colostate.edu/projects/century5/ Parton et. al, 1987).

These models need to be updated to better define the sustainable amount of crop residue that can be removed–taking into account more than just erosion and carbon sequestration in the soil. Research needs to be extended to include emissions of greenhouse gases such as nitrous oxide, methane, and carbon dioxide for various locations, crops, and management practices. For example, nitrous oxide has 320 times the impact of carbon dioxide in the atmosphere. Its significance must be accounted for along with alternative applications down the value chain.

In addition, removal needs to look at collecting the whole plant—both the grain and the remainder of the plant on the surface. Information for the life cycle analysis and life cycle inventory are especially needed. The impact on greenhouse gas emissions from removing some of the residue is currently being evaluated, but the results are incomplete.

Plant Science Opportunities

The application of biotechnology to plants opens up many possibilities:

- Increased yields of biomass per acre and per unit processed
- Improved composition, e.g., increased cellulose, lower lignin
- Enhanced processing, e.g., sugar distribution for improved hydrolysis
- Enzyme expression along with other co-products.

To realize these gains extended time for research, development, and deployment is required ranging from 3 to 10 years. The tools for implementation are well proven. In the 3 year time frame existing hybrids can be selected that will improve field yields and, with process development support, genotypes can be identified that make processing easier and lower production cost. Mid-term, enhanced processing yields could be achieved. In the longer term—7 to 10 years—the plant carbon can be redirected, changing the composition. Cellulose enzyme system expression or other co-products could also be expressed within this time frame.

Private companies are leading research on cash crops such as corn, soybeans, and wheat. International consortiums usually perform the cane research. Sugar cane is grown by reproduction, not seed, so intellectual property is difficult to control.

Public acceptance of genetically modified crops is a concern, but most believe fears will dissipate as more of the consumer benefits are demonstrated and if no adverse effects surface for existing genetically modified crops.

Biotech crop plantings continue to increase. Between 1996 and 2000, a total of fifteen countries have contributed to more than a twenty-five fold increase in the global area of transgenic crops. The accumulated area of transgenic crops planted in the five-year period 1996 to 2000 totals more than 300 million acres. In 2001 the number of farmers planting genetically modified crops is expected to exceed 5 million. The global area planted in transgenic crops is expected to continue to grow by 10% or more in 2001 (James, 2001).

Feedstock Business Model

It is generally recognized that a successful operation requires a win-win relationship between the local farmers and the processor. Unlike corn, the biomass feedstock is bulky, and transporting it long distances is not economically feasible. Local sourcing of feedstock material is needed to keep transportation costs minimal.

Based on the participant's comments, there is considerable education required to change management practices consistent for stover removal and overcome value judgments that do not match up with facts. A significant outreach effort will likely be needed to collect an adequate amount of feedstock.

Some participants felt that farmer investment in the production plant would be needed. While desirable, others pointed out that a previous attempt to use this approach by Heartland Fibers failed. Over the past decade Heartland pushed the concept to farmers in MN, OH, IN, IL, and NE before closing down. All their attempts to get farmers to invest in a new, yet-to-be proven venture were not successful. Once the concept is proven—such as corn to ethanol—farmers are willing to invest as the proliferation of farmer-owned corn dry mill plants shows.

A recent survey developed by NREL of 400 corn growers indicated that 74% were likely to sell stover for ethanol production. The opportunity for additional revenue was the main motivation. Since 71% had some rolling land and 43% were growing part of their crop on highly erodible soil, selective removal will be required. Only active farmers who planted 300 acres of corn in 2001 were included in the survey. On average, they planted 653 acres and had a yield of 145 bu/ac. More than half did not know what price they would need to sell the stover. The complete study is at www.ott.doe.gov/biofuels/pdfs/5993.pdf.

The participants also discussed pricing, quantity available, storage, and inventory ownership.

a. Pricing

Farmer perspective: The amount per acre is often used, and must be greater than $20/acre to attract interest. Previous experience with collecting stover for furfural production (Glassner et. al, 1998) indicated that adequate baled quantities could be delivered for $35/dt. To achieve this, the participants agreed that considerable communication is required, often on a one-to-one basis. Grower concerns that need to be addressed include value of nutrients, landlord reaction in terms of rent paid and possible restrictions, possible changes in crop management practices, and overall coordination of the harvest.

Processor Perspective: The processor wants to pay on the basis of sugar composition and other characteristics that enhance processing. Dirt accelerates equipment wear and is a serious problem. A penalty based on dirt and other foreign matter content is likely. The NIR analysis used by the soybean industry to pay based on oil content was one model referred to. The analytical work on corn stover to give rapid results fits well with this concept (Hames and Thomas, 2002). Still, more parameters may need to be measured that reach beyond NIR methods according to some participants.

For both the buyer and seller, an arrangement is needed that allows for innovations to be included in raising the price per acre to the farmer and lowering the price per ton paid by the processor.

There are three models for pricing feedstocks to examine:

- Corn, by the bushel
- Sugar cane, by the sugar produced
- Soybeans, by the oil present in the feedstock

Corn starch content is not a pricing driver for corn millers. The wet millers especially buy corn in large quantities—by the unit train load—and the logistics make identity preservation costly. Corn co-products add to the complexity. In contrast, sugar cane growers are paid on the basis of sugar processed, with the processor sharing revenues with the farmer. Soybean processors pay based on the oil content of each delivery determined from NIR analysis.

With biomass, the local connection between farmer and processor is similar to the sugar cane model, simplifying identity preservation. NREL analysis shows significant variation in the stover feedstock composition, which in turn impacts processing cost up to 20% (Ibsen & Ruth, 2001). It appears the economic affect will require payment based on composition, ease of processing, and product yield. Complexity of the payment basis may increase, depending on the co-products.

b. Quantity

Most participants agreed that a full size plant would process 800,000 dt/year, about 2,000 dt/day. Process equipment supplied for the wood pulping industry matches this scale. It is very similar to the type required for non-wood biomass processing. A plant 50% smaller results in some loss of economy, but not that much according to the participants. Therefore, careful study of the plant location is required to insure adequate feedstock is available. A 50 mile collection radius has proven manageable for truck transportation. The distance balances transportation cost with crop related weather risk for most situations that are not irrigated.

c. Storage and Inventory Ownership

No processor wants to have a large inventory listed as an asset with just one turn annually. Most corn millers operate with a 3 to 7 day supply of corn. The bulk of the inventory is expected to be carried by the farmer or a farmer owned entity.

Based on conversations with local farmer organizations in IL, IA, and NE, the potential processors in the colloquies believe they can deal with a single supplier group as an intermediary between them and the individual farmers. Either a co-op or other farmer owned entity would serve as the “feedstock elevator,” storing the material until ordered by the processor, and billing in the same way that grain elevators do now.

Initially this entity would likely be the vehicle to get grower commitments to supply the feedstock, working closely with the processor and other local stakeholders such as the USDA, NRCS, and Extension staff. The assignment is a sizable task. About 500,000 acres are needed when using 1.5 t/ac feedstock collected; the harvested amount used in the A.D. Little study. If each grower offers 200 acres, a total of 2,500 growers are required.

3. Economic Process

Feedstock cost was of lesser concern than process factors. There appears to be a consensus on its price. Some of the potential processors have met with local farmers who assured them that they can deliver adequate quantities of corn stover for $30 to $35/dt. While lower feedstock costs are desirable, the cost is acceptable if other processing cost targets are met.

Pretreatment is perceived to be most critical and feedstock pretreatment methods require the largest effort. Immediately coupling feedstock pretreatment and enzyme hydrolysis of the cellulose was judged as most important. It sets the basis for the rest of the process—fermentation and downstream processing. When pretreatment is done properly the latter two operations are simplified.

<u>Pretreatment</u>

NREL and a university based consortium are currently evaluating various pretreatment options. Industrial involvement in the selection is wanted.

There are many forms of pretreatment being considered. Some use hot water and forms of steam explosion, others use dilute acid and solvents. None are judged to approach the ideal pretreatment described in the colloquies:

> "A pretreatment that converts lignocellulosic feedstock into a cellulose substrate that is readily hydrolyzed into glucose by cellulase enzymes . . . by-products from the pretreatment do not inhibit the fermentation and these compounds can be recovered economically for value added products, along with simple hemicellulose derived sugars."

The enzyme conversion of cellulose is greatly effected by the presence of other components—lignin, forms of cellulose, xylans, arabinans, hemicellulose, acetyl groups, and others. The composition is dependent on the feedstock and to a lesser degree they vary in the same feedstock, depending on growing conditions, handling, and storage after harvest. Many by-products may be formed during the pretreatment. Some of these can denature protein and inhibit hydrolysis and fermentation.

The corn stover is not homogenous. Leaves and husks have a different composition than the stalk, and the stalk composition varies with the length and diameter. The bottom of the stalk contains more lignin than the top. . . and the pith has different physical characteristics than the fibrous exterior. Cobs may be present, introducing another variation. The degree to which they can all be pretreated satisfactorily under the same conditions is currently being investigated by NREL.

Until a universal pretreatment is available, process performance will be affected by changes in feedstock. Most participants expect the best pretreatment will occur when one feedstock is used. Even then, some tweaking of the process will be needed for variations in feedstock due to growing conditions, storage, and handling. The pretreatment conditions, the enzyme, or both will need to be adjusted to control the process within defined limits.

The ability to successfully pretreat multiple feedstocks adds process complexity. At least a macro understanding is needed. Taking a “black box” approach will not be successful. Conversely, a universal pretreatment is not likely until a molecular understanding is achieved.

<u>Cellulase development</u>
Cellulase enzyme knowledge was thought to be more in depth than any other family. They have been widely applied to textiles, detergent, and food applications. Still much remains to be learned and applied to improve their performance. Cellulase enzymes remain a significant cost component, but have decreased from \$0.50/gallon of ethanol to a current range of \$0.10 to \$0.30/gallon.

DOE awarded Genencor and Novozymes about \$15 million each to reduce the enzyme conversion cost by 10X in the years 2003 and 2004 respectively. Their efforts are focused on corn stover using NREL’s dilute acid pretreatment process.

Pretreatment affects the downstream performance, including enzyme performance. Pretreatment and enzyme hydrolysis processing must be linked to provide an enzyme substrate to Genencor and Novozymes that closely matches the full scale pretreatment scheme. If not linked, or if linked to a different pretreatment process, the enzymes developed may not meet the 10X performance target in the commercial plant.

Iogen is also developing a cellulose enzyme process for lignocellulosic conversion. The effort began in 1974 and has been partially funded by Natural Resources Canada. (The DOE provided \$600,000 in 1979.) Total investment in the program to date is \$65 million, including \$30 million in a 40 t/d pilot plant in partnership with Petro-Canada. The plant is in the start-up phase now. Due to difficulties with collecting corn stover during the narrow harvest window in Quebec and Ontario, their present feedstock is cereal straw grown in the western provinces. Other enzyme suppliers continue to evaluate the possibilities for this emerging market also.

<u>Fermentation Sugars</u>
Fermentation sugars now supplied from starch can be purchased for about 8¢/lb. The selling price will vary depending on corn and co-product prices. The DOE program with NREL sets a target price of 4¢ to 5¢/lb (Wooley, 2000 and Ruth, 2001). At this lower price a new fermentation platform for fuels, chemicals, and biopolymers should be possible.

The properties for the fermentation sugars become more important when moving from fuel ethanol to chemical production. For fuel ethanol, the downstream process can tolerate a high level of impurity based on small scale testing, because the impurities typically end up in the still bottom. Since these solids are high in potassium, phosphorus, and other compounds removed from the feedstock, they can be used as a soil fertilizer.

Production of chemicals and other value added products usually requires a consistent, higher purity stream for fermentation. Unlike ethanol, the cost of removing impurities in the downstream processing quickly becomes prohibitive. The purification equipment adds to the capital and operating cost. Usually a portion of the purification step is recycled, increasing process complexity. Disposal of the unwanted stream can also be expensive if it must be sent to wastewater treatment, landfilled, or removed from the plant air emissions. Preventing impurity formation in the pretreatment becomes much more important for these products than for ethanol.

Ethanologens and other microbes

There are multiple microbes and ethanologens, which can convert both C6 and C5 sugars to ethanol. At least four have been tested on mixed cellulose and hemicellulose hydroyzates for various periods on a small scale. Participants felt comfortable that one or more of these would be suitable.

Microbes are also under development for other chemical processes. Examples included Diversa's agreements with Degussa, Givaudan, BASF, Celanese and Dow, and Maxygen's agreements with DSM, Hercules, Cargill-Dow LLC, Novozymes, and Chevron. Again, with consistent fermentation sugars of sufficient purity, the participants felt that this development would be successful.

4. Process Validation

A continuous demonstration of the process is required to validate the engineering design for a full scale plant and reduce the risk. The total investment for a 2,000 dt/d plant is estimated to be about $200 million (Wooley et. al., 1999). In the event parts of the process require revision, the correction costs quickly become exorbitant—more than $100,000 per day when not operating.

NREL presented a timeline for process validation that matches the enzyme development schedule for Genencor and Novozymes. Other schedules were discussed also, with the intention of better identifying the activities and potential ways to organize and schedule. The issues included the following:

- Need—Access to capital, feedstock, and markets
- Feedstock evolution—Corn fiber as prologue to corn stover and other crop residues
- Size—How large to scale
- Boundaries—How integrated
- Cost—Capital and operating cost
- Organization—Consortium, partnering, or other
- Timeline to commercialization

Need

Some entrepreneurial biobased companies have attempted to move from one dt/day pilot plants that were partially integrated (no recycle streams) to a full size plant using process guarantees provided by the design engineering companies. The guarantees are expensive. Having guarantees has not helped their holders to access capital for “first-of-a-kind” biomass plants that have skipped the fully integrated process validation step.

The chances for the project to encounter problems are reduced after the process is demonstrated on an intermediate scale. The test results reduce the risk for potential investors and other stakeholders such as employees, feedstock suppliers, and customers. Continuous operation on a “semi-commercial” scale proves the design basis and better insures that the larger process design will produce a quality product that meets the customer requirements safely and within budget, and that complies with all environmental requirements.

Even when fundamental relationships are thought to be understood, a small difference that is magnified by 2,000 (the difference between one dt/day and 2,000 dt/day) can cause unexpected difficulties and lengthy delays. In addition to the possibility for cost overruns, there are related issues:

- Feedstock supply
- Plant organization
- Market development

a. Feedstock supply

The feedstock supply requires an inventory cost outlay of $20 to $40 million for crop residues. Some of this cost is expected to be carried by the “elevator-like” biomass supplier. As most, if not all, of the harvesting, collection, and storage of the feedstock needs to be performed prior to the plant start-up, feedstock suppliers need to be convinced the project is real before investing resources into the venture.

b. Plant organization

Similarly, the processor’s organization needs to be in place. Staffing the plant with qualified people requires potential employees to have some confidence in the outcome, especially if they are employed elsewhere or relocating.

c. Market development

While market development is not necessary for a commodity like ethanol, potential customers for other products derived from the fermentation sugars, or other co-products like lignin or fiber are likely to require trial quantities for evaluation. Testing often requires 40 to 80 ton quantities, beyond the capability of a lab scale pilot or even the one dt/day plant.

The economic penalty for not preparing the distribution channels for a significant step-change when the commercial scale plant comes on line can be significant. For example, a 2,000 dt/day plant produces 340 dt lignin in nearly 680 dt of residue each day, about 35 truck loads. If it is sold as an ingredient in dispersants for dyes, concrete, and paint—a current market for lignin from the wood pulping process—application testing on a large scale gives more assurance of market acceptance.

Feedstock evolution: Corn fiber to stover and other residues

Some participants thought that processing corn fiber successfully would readily lead to processing corn stover. While stover likely requires more severe pretreatment, processing issues would be readily solved by applying the lessons learned from studying corn fiber. This plan typically diverts the fiber from one of the four or more fiber washing systems operating in parallel in the wet mill to the lignocellulosic process. The corn fiber processing occurs—and some of the material is returned to the main stream while the sugars are fermented separately.

Other participants did not agree, expecting the transition from corn fiber to stover to require significant additional effort. . . . similar to modifying a corn mill to process barley or wheat. In addition to the differences in composition and pretreatment conditions mentioned previously, potential problems may be diluted to the point that they are not identified. Closing a material balance and dealing with recycle streams are other issues participants expected to be difficult to resolve.

Disagreement extended to the development timeline. Some felt the fiber development would shorten it since the intermediate step could be skipped. Others thought the schedule would need to be extended for this route since the fiber development and demonstration would occur first, and the stover would require significant new knowledge.

Size—How large to scale

A new process is generally scaled up in smaller increments at the beginning of development. After a bench top test in grams, it may be increased to kilogram size and then perhaps a ton per day scale. These tests are operated intermittently, in terms of hours and then usually extended to days and even months. More learning occurs and the scale-up can be done with less risk.

The scale factor depends on the unit operation and the amount of knowledge. To move from one dt/day to 2,000 dt/day, an intermediate step was considered prudent. There is less known about pretreatment, so a factor of 20 X to 50 X was considered appropriate. Much more is known about fermentation and 1,000 X or even 10,000 X scale-ups can be made.

There are no absolutes for scaling up a process. Each situation needs to be considered. Value judgments based on experience, complexity, technical knowledge, and relative risk are applied.

Iogen has been through this evaluation, and chose to install 40 dt/day. They are currently installing the third redesign of the pretreatment, illustrating the learning that occurs at an intermediate step.

Boundary—How integrated

All participants agreed that the plant boundaries need to include feedstock pretreatment and enzyme hydrolysis as stated earlier. The enzyme performance is significantly affected by the pretreatment. Fermentation sugars from the process can be evaluated off-site on a scale that the user is comfortable with unless the fermentation broth is recycled back into the process.

Recycle streams increase complexity. They need to be incorporated into the boundary when present. For example, if the hydrolysate is used for cellulase enzyme production, the enzyme production should be performed on site when the fermentation broth is recycled, and in the same proportion. Since this is the most economical enzyme approach, recycle will likely be required. The same holds for other downstream processing steps employed for purification or treatment.

Cost—Capital and operating cost

The capital cost for the intermediate sized plant was assumed to be about $30 million, with the total cost of capital and operations reaching $50 million or more, depending on revisions required during the demonstration stage. Operating cost could be $1.5 to $2 million for 12 months; about $500,000 for feedstock, and $500,000 for labor, utilities, and other direct cost. Technical support is additional, and can add another $1 million annually for analytical, engineering, and design work. The demonstration stage often requires two or three years.

Products from the fermentation sugars are not expected to offset much of the operating cost. If applied to ethanol, 40 dt/day is the equivalent of 3,200 gallons using 70 gal/dt yield and a $1.00/gallon credit totals about $1 million annually if distillation capacity is available. When replacing dextrose for fermentation sugars for enzymes or other products, the credit may be a bit more, depending on the dextrose price.

Organization—Consortium, partnering, or leasing

To demonstrate the technology prior to the first plant, participants discussed forming a consortium, partnering with others, and using a larger facility similar to the existing TVA and NREL one dt/day lignocellulosic pilot plants.

A consortium was seen as too expensive and complex to function and meet most potential member's needs. Participants already working in the area preferred partnering with those that could leverage their expertise. Funding the construction of a larger government facility, similar to the 40 dt/day Iogen plant and leasing it to others was not considered plausible.

a. Consortium

It appears the biomass industry is not yet at the stage where there are enough companies with the interest and resources to form a consortium to develop, design, build, and operate a plant for process validation. This is core technology for successful commercialization. Proprietary knowledge is heavily involved. The concept was most favored by those new to this technology. Potential processors already working in the area were not interested in joining for this purpose. Protecting intellectual property was their major concern.

Successful consortiums generally function well in mature industries that have a large financial base. Work is usually focused on non-competitive areas that include raw material supply, industry standards, safety, health, and environmental issues. They also work on pre-competitive issues that are process related. Anti-trust issues emerge when the scope exceeds these boundaries.

The semiconductor consortium, Sematech, is a successful example. Initially composed of U.S. companies including IBM, Intel, Hewlett-Packard, and Motorola it has expanded to include international membership. It was formed in 1986 to reinvigorate the U.S. semiconductor industry. After intensive lobbying, Congress approved its funding in 1987 that continued through 1996. Sematech has since expanded to international membership and 13 member companies of the $280 billion semiconductor industry continue their support. Additional information is at www.sematech.org.

b. Partnering

Participants saw partnering as the best route to protect and preserve intellectual property. For fuel ethanol process validation, most participants envisioned that partnering would occur between a technology supplier and a biomass processor.

The process validation for chemicals production is different. Chemical manufacturers expressed little to no interest in moving upstream—only wanting to purchase a consistent sugar for feedstock. Here partnering will likely occur between technology suppliers, biomass process fermentation sugar suppliers, and chemical producers.

With Iogen already operating a 40 dt/day plant to test their cellulase enzymes as part of the integrated process, the use of their facility presents an immediate partnering opportunity. They have expressed a willingness to test other cellulase enzymes as part of a business agreement. Iogen would perform the testing and report the results, retaining the intellectual property on how to make it work.

c. Leasing

Constructing a larger government facility for use by others is another possibility. The high cost was thought to be prohibitive for congressional or state funding unless new support was forthcoming. Timing would certainly be extended based on a small corn to ethanol production testing facility now under construction in Carbondale, IL with government funding.

Efforts to garner support for the corn starch to ethanol plant began in the 1980's among corn grower organizations. The initial plant design using proven process technology was completed in 1993. It is expected to be ready for operation in 2003. The $20 million construction costs for the 2 ton per day plant are entirely funded by the USDA and the State of IL. No industry money is being used. The users will pay the plant operating costs.

Commercialization timeline

There are multiple biomass commercialization plans underway. Figure 2 shows the stages to commercialization. The timeline proposed by NREL is shown in Figure 3 (McMillan, J., 2001).

Figure 2.
Proposed Stage Gate Review Plan

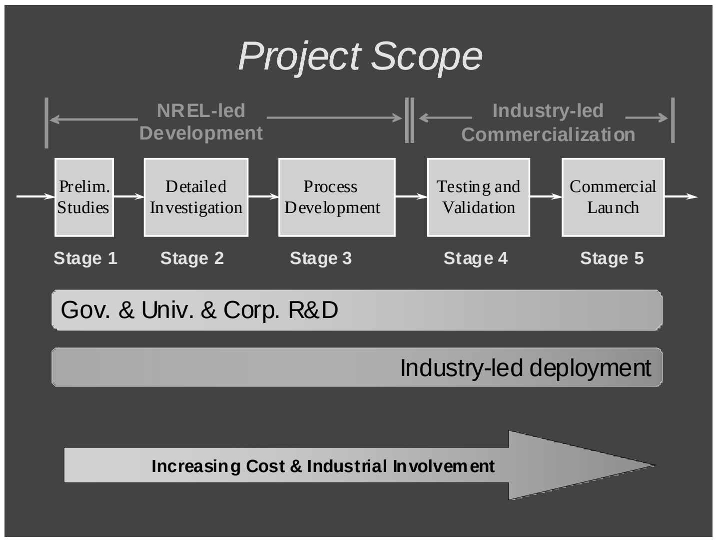
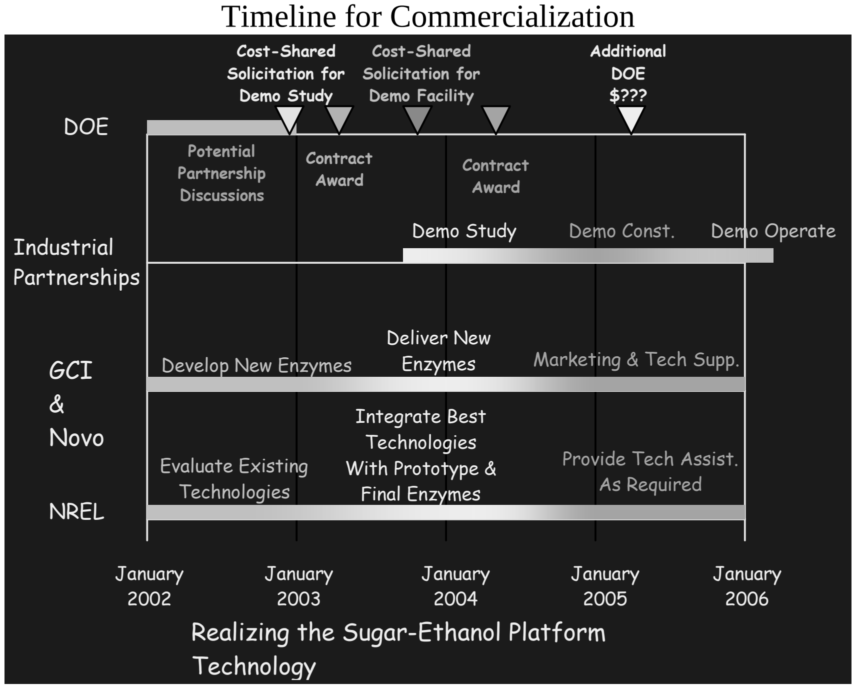


Figure 3.
Timeline for Commercialization



NREL's schedule matches up with the improved enzymes expected to be available in 2003 and 2004 from Genencor and Novozymes. Iogen is planning to have a fixed design for a commercial ethanol plant in 2004. Others have similar plans that may result in a commercial plant in the next 3 to 5 years. NREL is planning a meeting in January, 2002 to discuss these possibilities further.

a. NREL Schedule

The timeline presented by NREL accomplished its main purpose: to stimulate discussion. While the proposed schedule coincides with the delivery dates for improved enzymes expected from Genencor and Novozymes, additional time may be required to adjust the process and the enzyme as the development is further integrated. The time required can only be guessed—it will depend on the degree of understanding gained for parameters such as feedstock variation, equipment corrosion, xylose fermentation, and other unknowns.

Once the organization route for industrial participation in process validation is decided, the size and design of the next scale plant must be decided and built within the next 2 to 4 years. Setting the design for a full size plant in 12 months after the intermediate scale plant is ready to operate allows little time for exploring the process limits and any modifications. Based on other experience, this step can require 24 months or more before setting the design for a "first-of-a-kind" plant requiring a $200 million investment.

Successfully using corn fiber as a prologue to corn stover was thought by some to shorten the development timeline considerably. With sufficient data from the integrated development on a small scale, even 5 Kg/day, corn stover may be processed on a commercial scale with enough confidence—skipping the intermediate plant entirely. Instead of expending resources on the scale-up, they prefer to spend it on modifying the full scale plant as needed.

In conclusion, NREL indicated they would hold a meeting to discuss the timeline and related issues in January, 2002. All the colloquy participants will be invited to attend, along with others that have interest.

b. Iogen

Construction of Iogen's 40 dt/day plant began in the fall of 1999. It was ready for operation in 2000. It is now being modified for a third campaign. If this version proves successful over a 3 to 6 month evaluation, Iogen projects the construction of a full size 2,000 dt/day plant in 2004-2005. This is about the time the process validation begins for the adjusted NREL timeline.

c. Others

Most of the participants have biobased processes in various stages of development. Some expect to move forward within the next 5 years. To accelerate their commercialization efforts, they encouraged DOE to issue a RFP which sets a clear goal with flexibility in organizing. A request for letters of interest will precede that request in January 2002. This is further discussed in the Government Actions section.

5. Market Outlook

Fuel ethanol and chemicals are the target markets. The relatively huge scale for these makes the market for by-products difficult to develop and manage.

Fermentation derived products

The transportation fuel market segment—160 billion gallons for gasoline and diesel (ethanol can be added to diesel fuels as e-diesel)—offers the largest market. Chemicals represent a smaller but still significant segment.

Continued advances in biotechnology have resulted in the development of processing routes for chemicals that were once considered impossible. For example, DuPont and Tate & Lyle are operating a 100 ton per year 1, 3-propanediol to demonstrate large scale feasibility. Cargill-Dow LLC has invested over $300 million in a 150,000 ton polylactide plant that was started up in November, 2001. In both cases the fermentation sugar is dextrose produced from corn starch.

Participants said the price—8¢ to 9¢/lb—for fermentation sugars from corn and other grains limits commercialization. A lower sugar price—3¢ to 5¢/lb—would permit many of the products now produced from petroleum feedstocks to be moved to a biobased process.

The conversion of corn starch and other grains to ethanol receives $0.53/gallon ethanol subsidy. Conversion to chemicals and other products receives no subsidy. Since the subsidy favors the biomass to ethanol route, it is receiving some attention from present ethanol producers that have corn fiber on site. To take advantage of the ethanol subsidy and economies of plant scale, some may choose to produce both ethanol and chemicals initially.

By-products

Matching attractive markets for by-products with their supply is always difficult. Attempting this on the scale envisioned here was seen as a huge challenge by the participants.

Lignin was the most mentioned co-product. While there are some applications for lignins as a fuel additive and chemicals dispersant among others, these markets are relatively small when compared to the scale of fuel ethanol production. By-product quantities can easily exceed their market needs. As a result, most participants expected much of the lignin to be used as a boiler fuel.

Fiber for paper related applications is another potential product. Tree-free products have some market pull, but at an equivalent price when moving beyond a niche market now met with paper goods made from wheat fiber. Some fiber composite applications for the auto industry are also emerging, but the participants did not express interest in these areas for stover due to the scale of supply and the relatively limited market size—the same reason given for lignin derivatives.

6. Environment

Sustainable processes are an important consideration for the chemical industry. Going back 20 years or so, it was enough to be legal, and profitable. Now the chemical industry needs to be legal, profitable, and environmentally responsible. Despite major efforts to improve environmental performance, its manufacturing processes, while legal, have made it one of the world's largest industrial polluters. Going forward, it is faced with public policy that may adversely affect the industry unless it shows ecological and economic improvements.

To meet this challenge, some companies are pursuing sustainable development as an integral extension of their business. In terms of the "triple bottom line," projects must stand on the financial returns while meeting corporate environmental and social objectives and goals. "Natural capital" and "social capital" are more difficult to appraise. Natural capital is measured in environmental terms. Social capital measures are more qualitative.

Sustainable development and economic development are now accomplished by reducing the energy, emissions, materials, hazards, and risks of processes and products while improving yields and the use of renewables. While traditional petrochemical routes will remain dominant for the next ten years and longer, renewable feedstocks are emerging for some processes.

Cleaner technologies like biotechnology are being emphasized—e.g., placing biotechnologists with traditional process design people to create new technology platforms. The effort is likely to speed up as greenhouse gas emission rules are implemented. Participants thought carbon credits—some form of carbon related emission trading—would emerge. Carbon value estimates varied widely from $8 to $100/ metric ton of carbon equivalents.

The triple bottom line refers to cash, natural and social capital. Businesses currently recognize cash capital as all tangible assets. The triple bottom line has evolved out of a concern that there are two other forms of capital contribution not normally accounted for: "social capital" and "natural capital."

Natural capital represents the resources in the form of raw materials, plants, and other resources. Social capital is the human capital invested by people—employees, contractors, suppliers, and advisors—directly into the business and the investment by the social systems that support the business—schools, government agencies, and institutions—that provide the framework within which a business exists (Elkington, 1997 and 2001).

Sustainability from a corporate perspective results from producing a positive and balanced return to all three of these sources of capital—the triple bottom line.

Novozymes makes an annual report on the triple bottom line (www.novo.dk/es00/). For Dow's perspective see the CEO's address to the Green Chemical Foundation at: www.dow.com/dow_news/speeches/spe_lauzon_may.html.

7. Conclusions

The program to commercialize biomass to ethanol is largely on track. Plans to reduce feedstock costs by nearly 50% are in place. Enzyme and ethanologen development continue as planned. The two largest issues remaining are:

- Integrating the process development
- Attracting industrial participants to co-fund the validation stage

More integrated development is needed before risking an investment of about $200 million on the first plant. This development needs industry direction and participation. To overcome these barriers, establishing a "sugar platform" using the enzyme hydrolysis route under development by NREL and others is most promising.

The risk is reduced by operating an intermediate sized plant continuously to validate the design. The validation costs are high—$40 to $50 million—requiring industry partners with financial and technical resources to move ahead even if future government funding and technical support declines.

Developing a process that provides fermentation sugars for producing fuel ethanol AND other chemicals expands commercialization interest to include the chemical industry. The industry has the required resources and motivation to participate in the development. Their investment in R&D can accommodate the intermediate plant funding. Biomass replaces petrochemical feedstocks, reduces price volatility, and provides a more sustainable process.

<u>Feedstock</u>

- Corn stover continues to be the most likely feedstock along with cereal straw. Sugar cane and switchgrass are likely to emerge outside the corn and wheat belts.
- One-pass harvest and bagasse type storage of corn stover are likely to return more than $20 per acre income and reduce the delivered feedstock cost to $25/dt.
- Sustainable harvest issues require more study—extending the present knowledge to better define the removal impact using life cycle analysis.
- Plant science offers significant opportunities that are most likely to be realized in the mid- to long-term; 5 to 10 years in the future.

<u>Economic Process</u>

- Integrated process development is required. Industrial partners are needed to lead the development direction. Pretreatment is the most critical unit operation.
- Pretreatment and enzyme hydrolysis processing must be linked now to provide an enzyme substrate to Genencor and Novozymes that closely matches the full scale

pretreatment scheme or the enzymes developed may not that meet the 10X performance target in the commercial plant.

- A small, integrated corn stover feedstock process must be operated continuously, 24/7, to provide mass and energy balances and better determine the following:
    - o feedstock variation effect
    - o pretreatment condition limits
    - o enzyme hydrolysis
    - o fermentation microbe performance
    - o design for next plant scale
    - o cost estimate

  *The size is between a kilogram and one dt/day feed.
- A multiple disciplinary approach that couples biotechnology and chemistry with process engineering will achieve best design and cost

<u>Process Validation</u>

- Following the small scale demonstration, an intermediate scale plant is needed to reduce risk. For products other than fuel ethanol, semi-commercial quantities are needed for market development and stakeholder confidence.
- The scale-up is likely to be 20X to 50X for the pretreatment step and 1,000X or more for fermentation. The cost is estimated to be about $50 million.
- The operation cost can be more than $1million per year and it may not have much, if any salvage value upon completion.
- It needs to operate long enough to give design confidence—closing carbon and other material balances, establishing process yields and stream composition, testing materials of construction and yields, and providing more fundamental and macro knowledge.
- Wet millers may be able to validate corn fiber for much less, but it is a doubtful prologue for corn stover. Corn fiber lignin composition is just 1% or less and it hardly qualifies as a lignocellulosic feedstock.
- Partnering appears the most likely route for validation. This best preserves intellectual property. The essential components for consortium—a mature industrial base and a non-competitive mission—are lacking.
- Constructing a government facility to lease to users is not plausible for the timeline and existing support. For this to occur, the technical community needs to tell Congress what is required and let Congress set the spending priorities.

<u>Market outlook</u>

- Low cost fermentation sugars —3¢ to 5¢/lb—permit many of the products now produced from petroleum feedstocks to be moved to a biobased process.
- Matching attractive markets for by-products with their supply on the scale envisioned here is a huge challenge.

<u>Environment</u>

- Biomass processes match up well with the chemical industry's need to move from price volatile petroleum feedstocks to more stable and sustainable feedstocks.
- Cleaner technologies like biotechnology are being emphasized. The effort is likely to increase as greenhouse gas emission rules are implemented.

- Participants thought carbon credits—some form of carbon related emission trading—would emerge. Carbon value estimates varied widely, from $8 to $100/ metric ton of carbon equivalents.

7. Recommendations for Government Actions

Participants look for government actions to help reduce the risks associated with building the first plant. The major areas for assistance are:

- Process development—continuing to integrate the process, providing additional understanding at a fundamental and macro level
- Sustainable feedstock collection—going beyond erosion control and carbon sequestration in the soil
- Process validation—funding multiple process validation efforts via RFP's

NREL should follow through with the January, 2002 meeting with colloquy participants and others interested. Other recommendations include the following:

Process development

The national laboratories, particularly NREL, should continue process development with a focus on corn stover. These activities are best directed by industry to commercialize the results. Partnering with industry is needed, and NREL can pass intellectual property to their industrial partners.

Development results should be easier to retrieve. NREL, along with other national laboratories generates many biomass related reports. Locating these reports is often difficult. Though good progress has been made in facilitating their retrieval on the web, more is needed.

Both the USDA Agricultural Research Service (ARS) and the national laboratories have overlapping process development programs. Duplication of these development efforts within the national labs and the USDA ARS should be reduced, if not eliminated. There is much to be done, and industry partners should provide the direction.

Related process recommendations include the following:

- Consider ways to make the process model more useful, e.g.:
    - Develop multiple scenarios with industry
    - Run them in an iterative manner using feedback to make adjustments
    - Incorporate new information regularly and publish the new results

- Conduct the Genencor and Novozymes enzyme development with substrate expected to be produced from commercial process to best insure the enzyme matches

- An early indication is needed to see if processing corn fiber is a prologue for processing stover and can shorten process development time.

Sustainable feedstock collection

Feedstock sustainability issues require better resolution. No processor wants to be associated with a harvesting operation that has large gaps in the knowledge of the potential impact of removing the biomass, particularly corn stover. Previous studies of crop residue removal need to be revised and include other factors in addition to soil erosion and carbon sequestration.

Researchers within the USDA, DOE, and EPA should move quickly to answer the current issues that revolve around one-pass harvest, no-till, fertilizer impact under removal scenarios. Validated models that help resolve “sustainable harvest” issues are needed. They must be capable of answering local questions—especially across the corn belt—and be available within the commercialization timeline.

Other feedstock related recommendations are as follows:

- Continue efforts to lower corn stover’s delivered cost with one pass harvest and bagasse type storage
- Continue to develop and demonstrate the analytical methods for composition measurement and relate to ease of processing
- Examine the potential for high fiber sugar cane

Process Validation

The next step for commercialization—process validation—is expensive. Participants suggested multiple RFPs should be funded. To frame the RFP contents, preliminary meetings with industry were suggested for defining the contents. While no consensus is expected, the solicitation of industry comments is expected to produce better results.

Multiple RFPs are needed. Competitors will not partner for any number of reasons, including anti-trust laws. Genencor, Novozymes, Iogen and any other enzyme supplier would need to respond separately (for example, joining up with a potential processor and perhaps a microbe supplier). Other competitors such as microbe suppliers like Maxygen and Diversa would respond in a similar way.

The RFPs should be coordinated within Energy Efficiency and Renewable Energy Offices and with other departments. The objective and goals for the RFP should be clearly stated. Supporting information should be included that comprehensively covers the current process technology base. Adequate time to respond is needed. Organization of the effort needs to be flexible. The selection should be based on the ability of those with resources to move forward in the event funding is not available from Congress in subsequent years. Another suggested criterion is the ability to clearly extend the outcome to a large market segment.

The selection criteria should be set to help insure that partners have the necessary resources to complete the work. It should be clear that funding over multiple years may not be available. Since Congress fixes the Federal budget on an annual basis there is no assurance DOE funding will be adequate in future years to support the projects.

Selection should also be based on the ability to clearly extend the outcome to a large market segment without much additional work. For example, one criterion could be that the feedstock selected along with the pretreatment process, hydrolysis to sugars will be adequate to supply 5% or more of the transportation fuel market along with meeting the needs of chemical and polymer producers for relatively consistent and pure fermentation sugars.

<u>Other actions</u>

a. Loan guarantees

Like corn, the process needs incentives and support until products can stand alone. In addition to providing matching funds, some suggested that loan guarantees be considered for the first generation of plants. Others said loan guarantees can be a license to fail even with rigorous precautions in place. Most believed the money is better spent performing process development work.

b. Earmarks for biomass projects

The increased number of mandated line items, "earmarks," in the federal budget for biomass related projects is threatening the ability of DOE to support biomass commercialization. Many of the items that are funded are of questionable merit. To counteract this approach, strengthening the interaction between USDA, DOE, NREL, and industry to jointly develop biomass commercialization plans led by industry is desirable. Industry needs to then communicate technical needs and benefits to Congress.

Acknowledgements

Our thanks to Billie Christen, NREL, for arranging all the colloquy details, to all the participants for sharing their thoughts, and to the DOE Office of Fuels Development for funding the study.

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Additional references are available at the Biofuels web site:
http://www.ott.doe.gov/biofuels/esp_background.html

Appendix A

The 2000 R&D spending for some of the colloquy participants is given in Table A below:

Table A

Annual Spending on Research & Development

Year 2000 R & D Spending, $ Millions			
Company	Sales	R&D	% Sales
ADM	20,051	24	0.12
DuPont	28,406	1,776	6.3
Dow	23,008	892	3.9
Hercules	3,152	46	2.5
Rohm & Haas	6,004	259	3.8

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